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Preliminary Study for Beam Transport Line Upgrade in KAHIF

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1. Introduction

For the development of nuclear fusion reactors, it is essential to develop materials can withstand high-energy neutron irradiation environments of hundreds of displacements per atom (DPA) and verification of their performance [1-2]. Testing with actual 14 MeV fusion neutrons or neutrons of similar energy would be costly including a new facility construction [3]. It would be take a long time and cost even using the existing research reactor. These problems can be solved with heavy ion accelerator which alloy for fast irradiation and study of neutron irradiation behavior like the KAHIF in Daejeon. It can provide the stable ion beam energy by 178 keV/u and the tests using He ions and Ar ions are utilized not only the fusion material research but also the material development for the next generation nuclear power plant or nuclear fuels. Currently, the facility is focused on the supply Fe ion beam for the Fe-based structural material of fusion and fission reactors. In order to generate the Fe ion beam, the **m**etal **i**ons from **vo**latile **c**ompound (MIVOC) method has been adopted in the ion source [4]. To be sure the Fe ion beam transportation using the current beam line has been studied by TRANSPORT code [5]. Besides the studies on the generation and the transport of Fe ion beam, the test chamber system also has been required to upgrade of test chamber. One of the upgrade purpose is the changing the sample heating system, for example the ramping and cooling speed of the sample baking temperature, the maximum temperature of the sample heating, and the method of the measuring the sample temperature. These improvements need the change the heater type, the material of the chamber, and especially the increase of the chamber size. And the target chamber system is closely related with the medium energy beam transport (MEBT) line in KAHIF, the design of the new chamber should be considered with the MEBT line design. The plan of upgrade MEBT line including the target chamber system is presented in this paper. The study of the beam envelope and the quadrupole magnet (QM) system in MEBT line is mainly described.

2. Motivation

For the various ion beam irradiation tests, the demand of the enlarged test conditions has been required. Higher sample baking temperature (up to 900 ℃), the vacuum system for fast replacement, the monitoring of the sample temperature, and the additional beam diagnostics will be help to provide the more test cases. This leads the new test chamber system. In order to replace the target chamber, the more physical space in beam line is required. Renewal of the MEBT line is the only way to secure the space for the new target chamber. The schematic diagram of the beam line upgrade is described in Fig 1. In this paper, the first stage of the plan which is the design study of beam line components is mainly presented.

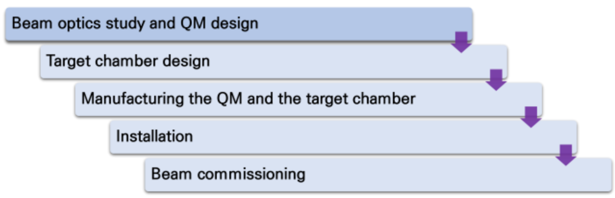

Fig. 1. Schematic diagram of MEBT line upgrade plan.

Figure 2 shows the layout of KAHIF beam line and the components of MEBT line. The MEBT line consists of the faraday cup (FC), the steering magnet (SM), the doublet magnet (quadrupole magnet 1 and 2), the target chamber (TC), and the re-buncher (RB). The length from the RFQ flange to the target chamber is limited by around 2.0 m as shown in Fig 2.

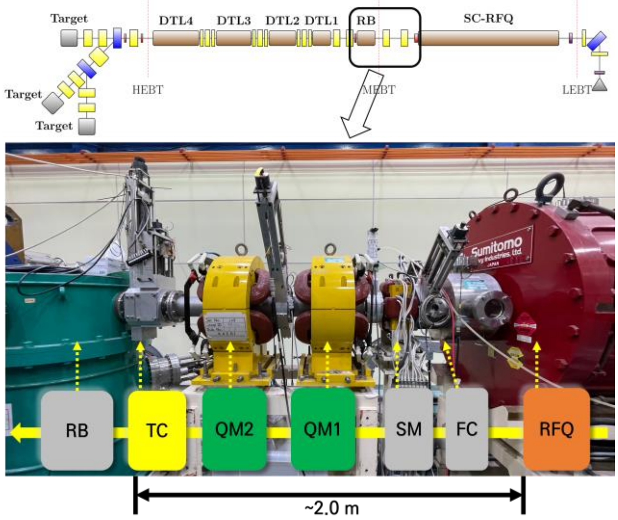

Fig. 2. Layout of KAHIF beam line (top). The picture of MEBT beam line of KAHIF (bottom). The beam propagates from the right to left direction in this picture.

The conceptual design of the new target chamber is shown in Fig 3. The diameter of the new chamber is required 500 mm in minimum concerning the heat radiation from the sample. The beam diagnostic instruments and easy access port for sample replacing will be considered. The detail design will be started after the design study of MEBT line as shown in Fig 1.

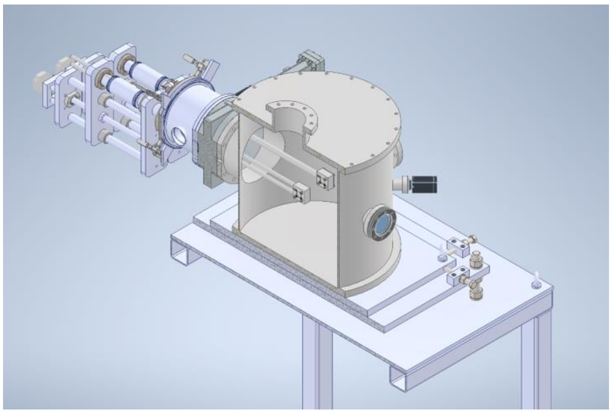

Fig. 3. Conceptual design of the new target chamber.

The main purpose of this preliminary study is to secure the space for the new target chamber. In order to achieve the goal, the replacement of quadrupole magnets in Fig 2 is only possible option. The parameters of the doublet magnet are summarized in Table 1. The new doublet magnet design could be possible more compact size than the current one by reducing the core length. The beam transport has been studied along the different effective length of the magnet.

Table I: Main parameters of the quadrupole magnet

Parameter	Value	Unit
Number of magnets	2	-
Max. field strength	12	T/m
Core length	0.35	m
Effective field length	0.2	m
Bore diameter	58	mm
Max. current	300	A
Max. voltage	30	V/magnet
Max. power	9	kW/magnet
Number of water circuits	4	
Water flow rate	12.5	l/min
Water pressure drop	4	kgf/cm^2

3. Beam line simulation results

The beam envelopes of MEBT line are studied by TRANSPORT code. First, the field gradients of the quadrupole magnet for beam transport are simulated along the effective length of the quadrupole magnets. The results of the simulation are shown in Fig 4. For the conservative simulation, the a/q is imported as 28 which is the maximum limit of RFQ. The QM 1,2 are located in MEBT line as shown in Fig 2. And the QM 3, 4 are located after the RB chamber for matching the beam optics from the RFQ to DTL1. The beam transport simulation is considered the matching condition from the RFQ outlet to the DTL inlet. The input parameters of the code are the same except the effective length of the QMs.

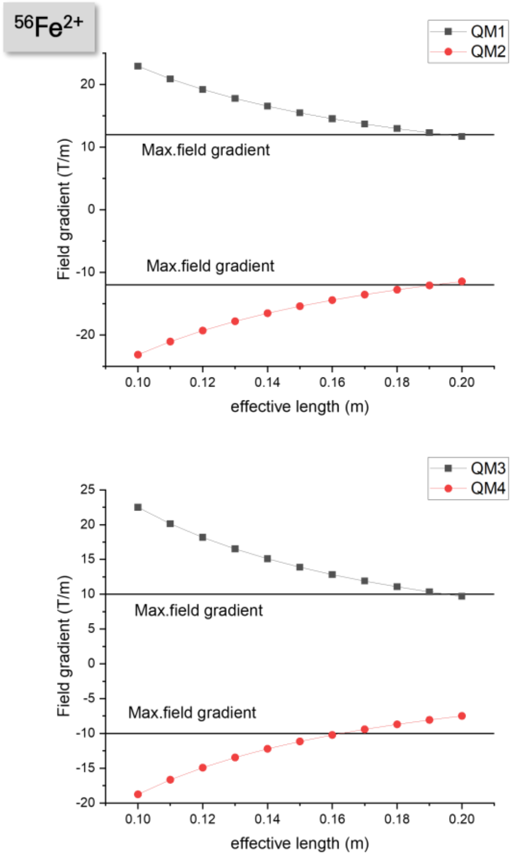

Fig. 4. Simulation results of TRANSPORT code for Fe^{2+} ion beam case. The charge to mass radio is considered 28 for this simulation. The positive and negative direction in vertical axis are corresponding the focusing and defocusing, respectively.

The maximum limitations of the field gradient are 12 T/m for QM 1, 2 and 10 T/m for QM 3, 4. The field gradients which are the cases for the effective length under the 0.19 m are exceed the limitation as shown in Fig 4. However, the results in Fig 4 are the cases of a/q=28. Typical value of a/q is 4 for He and Ar beam service in KAHIF. The charge to mass ratio of Fe ion beam is not optimized for beam service, only the range of ratio is decided in 3.5 ~ 5.6. The simulation results for the cases of a/q ratio in 3.5 ~ 5.6 range are described in Fig 5. The field gradients are satisfied the maximum limit over the effective length range from 0.1 m to 0.2 m in Fig 5. The beam transport envelopes are also studied and the results are described in Fig 6. The top graph in Fig 6 presents the case of effective length 0.1

m and the bottom graph indicates the case of effective length 0.2 m The beam transport envelops are matched in both different effective length cases. In each case, the charge to mass ratio values are considered as 2, 4, 4.4 and 28.

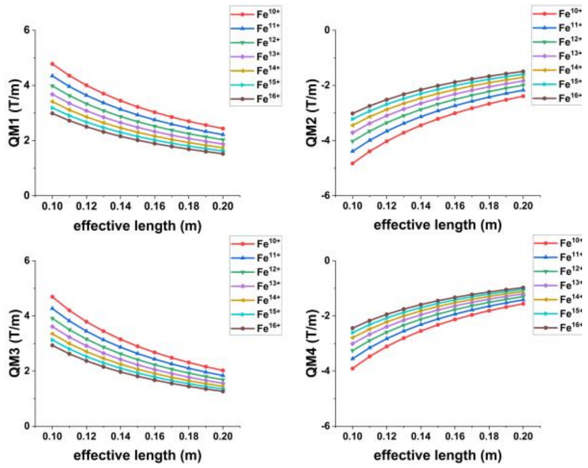

Fig. 5. Results of the simulation code. The field gradients of the QMs over the effective length are presented. For various cases of the charge to mass ratio are considered for beam transport.

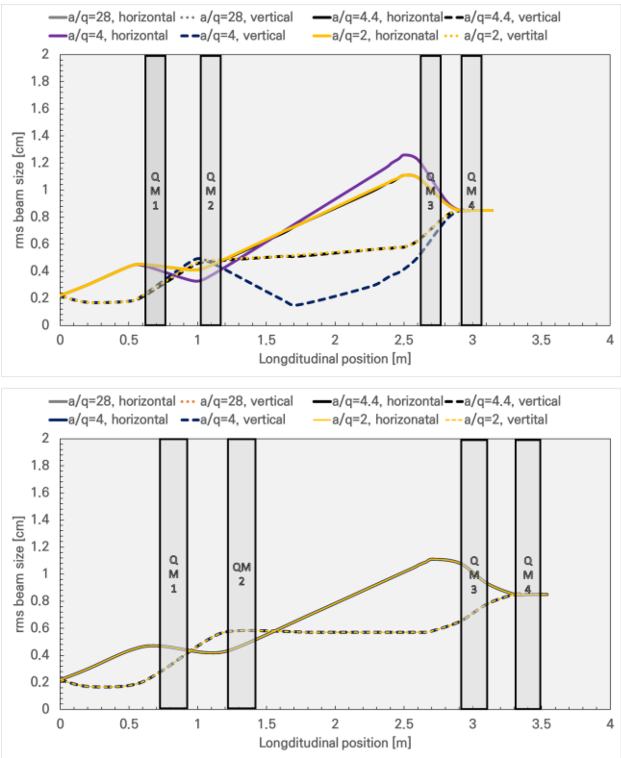

Fig. 6. Beam envelopes results from the simulation code. The effective length are used 0.1 m (top) and 0.2 m (bottom). Three values of the charge to mass ratio are considered in each graph.

Based on these field gradients over the effective length in terms of the charge to mass ratio, the design of the doublet magnet will be started. The power supply and the water-cooling system for the quadrupole magnets will be utilized the current installed systems. Even the effective length is shorten based on the simulation results, the engineering design of the quadrupole magnet with the current utility system of KAHIF makes the effective length longer than the simulation value by the optimal design process. The detail specifications of the quadrupole magnet will be studied for the next step of the plan.

4. Conclusions

Simulations of the beam transport code are performed for design the new doublet magnets in KAHIF MEBT line. The ion beam envelopes which is usual operating for the irradiation test, the charge to mass radio 4, are not influenced by the change of the effective length of the quadrupole magnets in the beam line by the simulation. Based on this study, the design of the doublet will be started for upgrade plan of MEBT line in KAHIF. Also, the design of the new target chamber will be progress.

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